CHAPTER C.7
LCA BOX MODEL CALCULATIONS

William Nuttle[1]

[1] *Eco-Hydrology, Ottawa, Ontario*

7.1 Background

The salinity and residence time calculation module provides a rational method of scaling results of the hydrodynamic numerical simulations during preliminary assessment of restoration plans at the basin level. Results of the hydrodynamic simulation provide critical inputs for desktop calculations of water quality, habitat use, and habitat switching.

The desktop tools described here serve two functions. First, they provide order of magnitude characterization of altered basin hydrology. Some of the restoration measures under study represent drastic changes to existing hydrologic drivers in the coastal hydrologic basins. The order of magnitude analysis will guide analysts in choosing an appropriate approach to evaluate the hydrologic, water quality, and ecological conditions that will result from such changes.

Second, the desktop tools provide a method for approximating the response of aggregated salinity patterns and residence times for a range of alternatives, *i.e.* various combinations of diversion size and location. The logistical requirements of setting up, running, and interpreting results from numerical hydrodynamic simulations are incompatible for direct application of the numerical models in a desktop planning environment. The desktop models allow for an approximate prediction of salinity and residence times based on the hydrodynamic model results for a few, strategically defined benchmark scenarios.

7.2 Index Models (Order of Magnitude Characterization)

7.2.1 Approach

The index models provide an indication of the degree to which a restoration alternative alters the water balance and flow conditions without requiring the application of detailed hydraulic calculations. The approach is based on calculation of a set of indices, each characterizing the relative scale of different water fluxes. These indices are applied basin-wide. Results at this analysis level guide the approach to projecting future, with-project conditions needed for evaluation of project benefits.

7.2.2 Assumptions

The underlying assumption is that gross features of salinity and flow for a basin are controlled by the magnitude of the net freshwater input to a basin compared with the volume of water contained in each basin and the volume of water exchanged by tides. Assessment of altered flows is based on the assumption that conveyance characteristics in

the existing channel network are developed to accommodate existing broadly defined, tidally driven flows.

7.2.3 Implementation

Implementation of the index models requires that the following information be assembled for each hydrologic basin:

A	area of the basin
V_W	volume of water in the basin
V_P	tidal prism - change in volume of water in basin between high tide and low tide
V_Q	net freshwater supply – daily average of freshwater diversions plus volume of rainfall minus volume of evaporation
$V_S(t)$	record of volume of water in a basin versus time during the recession of a storm surge, such as following a hurricane.
S_X	characteristic value of salinity at the mouth of the basin

The time series of volume change during recession of storm surge is analyzed by fitting an exponential function of the form;

[1]

$$V_S(t) - V_W = [V_S(t=0) - V_W] e^{-\alpha t}$$

The value of α characterizes the basin-wide, overbank conveyance so the net discharge from the basin is a function of excess water volume remaining in the basin;

[2]

$$Q_{NET} = \frac{dV_S}{dt} = -\alpha [V_S(t=0) - V_W] e^{-\alpha t}$$

The information above is used to calculate the following indices:

τ	$V_W/(V_P+V_Q)$	residence time; days for freshwater flow and tidal flushing to replace volume of water in basin.
S^*	$(S_X V_P)/(V_P+V_Q)$	characteristic salinity.
η	$V_Q/(\alpha A)$	super-elevation due to discharge; increase in mean water level relative to sea level needed to convey net freshwater discharge.
ξ	V_Q/V_P	channel capacity; values much less than 1.0 indicate that net freshwater discharge can be accommodated within existing channel network.

7.2.4 Output

The above indices are calculated for present conditions in each basin and for each restoration project investigated in that basin. Comparison of index values for present conditions with index values for with-project conditions provides a heuristic measure of the degree to which each restoration project drives hydrologic, hydraulic, and salinity conditions in a basin away from present conditions. If index values with-project are comparable in magnitude to present conditions, then it is justified to project future conditions in the basin based on hydrodynamic and salinity models calibrated for present conditions. If index values with-project deviate significantly, *e.g.* factor of 10 or more,

from present conditions, then projection of future conditions must employ a different approach. Alternative approaches include analog basins selected so that index values match the altered index values, and employing numerical models calibrated to predict changes in estuarine structure and function across a range of estuaries.

7.3   Box Models

7.3.1   Approach

To approximate the response of salinity patterns in each basin, results of the hydrodynamic model simulations are used to calibrate a mass-balance salinity model. The mass-balance model calculations will be implemented with a weekly or monthly time step, depending on requirements of the other desktop modules. The number and location of cells defined to implement the mass-balance salinity calculations within each basin will also reflect the needs of the other modules, as well as the mixing characteristics apparent from the hydrodynamic results. The mass-balance approach to predicting salinity response was previously used in Barataria Bay (Wiseman and Swenson 1989).

The mass-balance model calculations are implemented in a spreadsheet format. Calibration of the mass-balance models establishes "average" mixing characteristics in each basin, defined over the range of conditions represented by the hydrodynamic scenarios. In the desktop application, the analyst can alter the magnitudes and spatial distribution of hydrologic inputs, but the bathymetry, the model structure, and the calibrated mixing characteristics of the basin, retain their calibrated values.

7.3.2   Assumptions

Application of mass-balance models for desktop prediction of salinity and residence time relies on the following assumptions:

- salinity variation within each hydrologic basin of the LCA can be represented approximately by a series of fully mixed cells.

- Transport and mixing occur between adjacent cells at a constant rate which only depends on the difference in concentration between them.

- The net, long-term effect of tides, hydrologic forcing, and wind on mixing within the estuary can be represented by a constant exchange flux, i.e. mixing processes do not display a strong seasonality.

- Detailed simulations with hydrodynamic models provide an accurate representation of the detailed mixing and transport processes that affect salinity. (Note that this may not be possible if analysis based on the index models indicates that altered hydrology of a basin for a restoration scenario deviates significantly from (present) conditions for which a hydrodynamic model can be calibrated and validated.)

- Periods of simulation with the hydrodynamic models are long enough to capture the range of temporal variation in mixing and transport processes.

- Likewise, the number and variety of diversion scenarios covered by simulations with the hydrodynamic models capture the range of variation in mixing and transport processes as these might be affected by the diversions.

7.4 Conceptual Model and Implementation

Mass-balance models parse the estuary into a series of well-mixed water bodies, cells. Salinity varies in each due to dilution from the net input of freshwater (runoff and diversions, rainfall, and evaporation) and from the effect of dispersive exchange with adjacent well-mixed water bodies, Figure C.7-.1. The well-mixed salinity in a cell at the end of a model timestep can be calculated directly from the salinity at the beginning of a timestep, the salinity and volume of water advected into the cell, the net amount of salt exchanged with adjacent cell, and the volume of rainfall and evaporation occuring in each timestep, Equation 1. The salinity in adjacent cells is either known, *i.e.* from a time series of observations, assumed to be constant, or calculated.

[1]
$$S_{i+1} = \frac{S_i V + (S_R)_i (V_R)_i + \left[(S_X)_i - S_i\right]V_X}{V + |V_R|_i + (V_P)_i - (V_E)_i}$$

The model parameter V, the volume of each cell, is estimated from the known bathymetry of the estuary. The volume of exchanges between adjacent cells is estimated by calibrating the model to reproduce a time series of salinity values. The calibration data set comprises samples of spatially aggregated salinity values from the hydrodynamic model(s). The time series of spatially aggregated salinity values are sampled at the end of each model time step, *i.e.* at weeks-end for a weekly time step in the mass-balance model calculations.

7.4.1 Inputs from Other Modules

The mass-balance models require input from the hydrodynamic models. Spatially aggregated salinity results from the hydrodynamic models serve as the calibration data set for determining the unknown exchange volumes between adjacent cells, Figure C.7-.2. Calibration also requires spatial aggregation of the hydrologic fluxes (runoff, diversions, rainfall, and evaporation) used as input to the hydrodynamic model simulations. It is also possible to calibrate the mass-balance models using observed, baseline (no project) data from the estuary.

7.4.2 Outputs

The mass-balance models provide predictions of aggregated salinity for each water body at the end of each calculation time step.

The mass-balance models provide direct time series of aggregated salinity values (spatial averages within cells). It is also possible to extract residence time information from this output, because the calibrated models contain information on the mean mixing characteristics in the basins. For example, this can be done by using the mass-balance models to simulate the decay of a conservative tracer introduced into a cell of the model, Figure C.7-3.
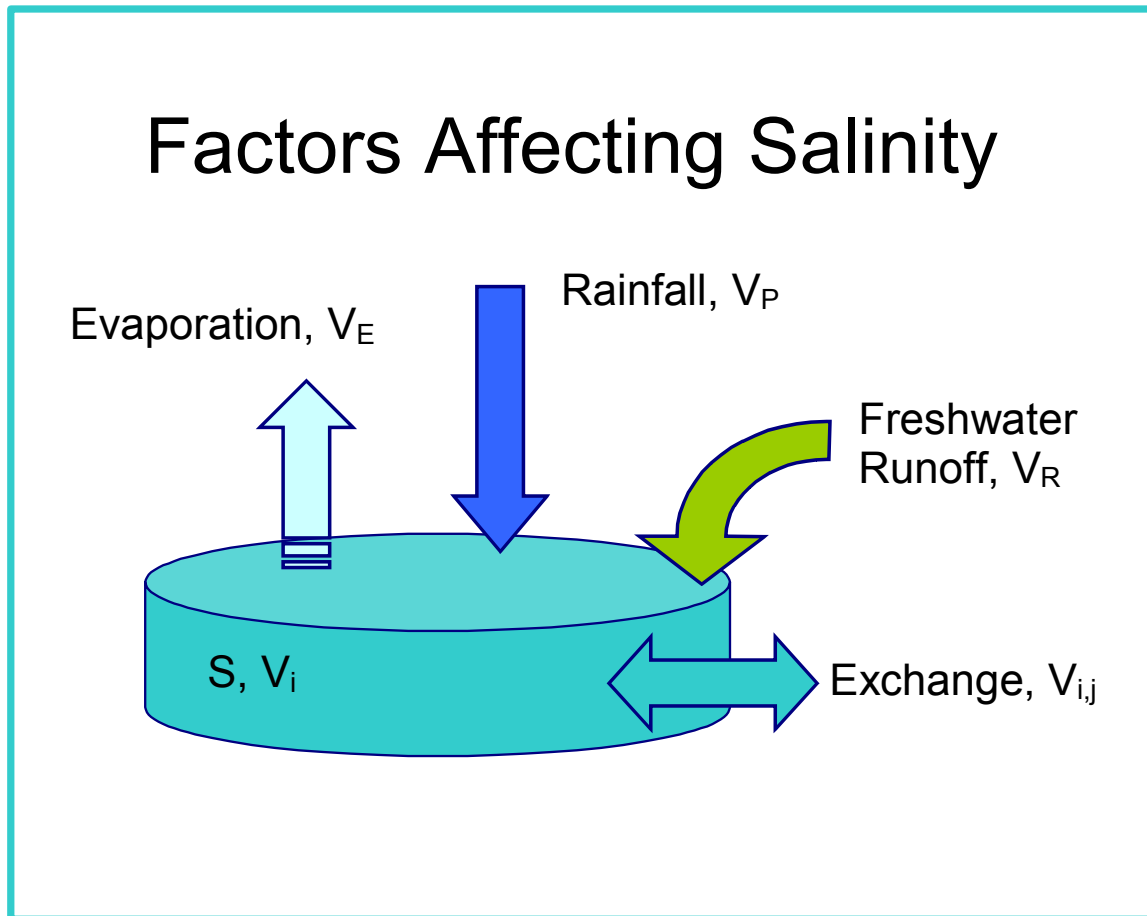
Figure C.7-1 Factors affecting aggregated salinity in each region

Development of Desktop Salinity and Flushing Models

1. Design scenarios based on "average year" conditions and restoration activities.

2. Numerical hydrodynamic models produce detailed results.

3. Aggregate results at level compatible with other modules.

4. Calibrate box models to match aggregated results.

5. Desk-top models predict salinity at aggregated level

$\overline{\overline{H}}$ Hydrologic fluxes aggregated in space and time

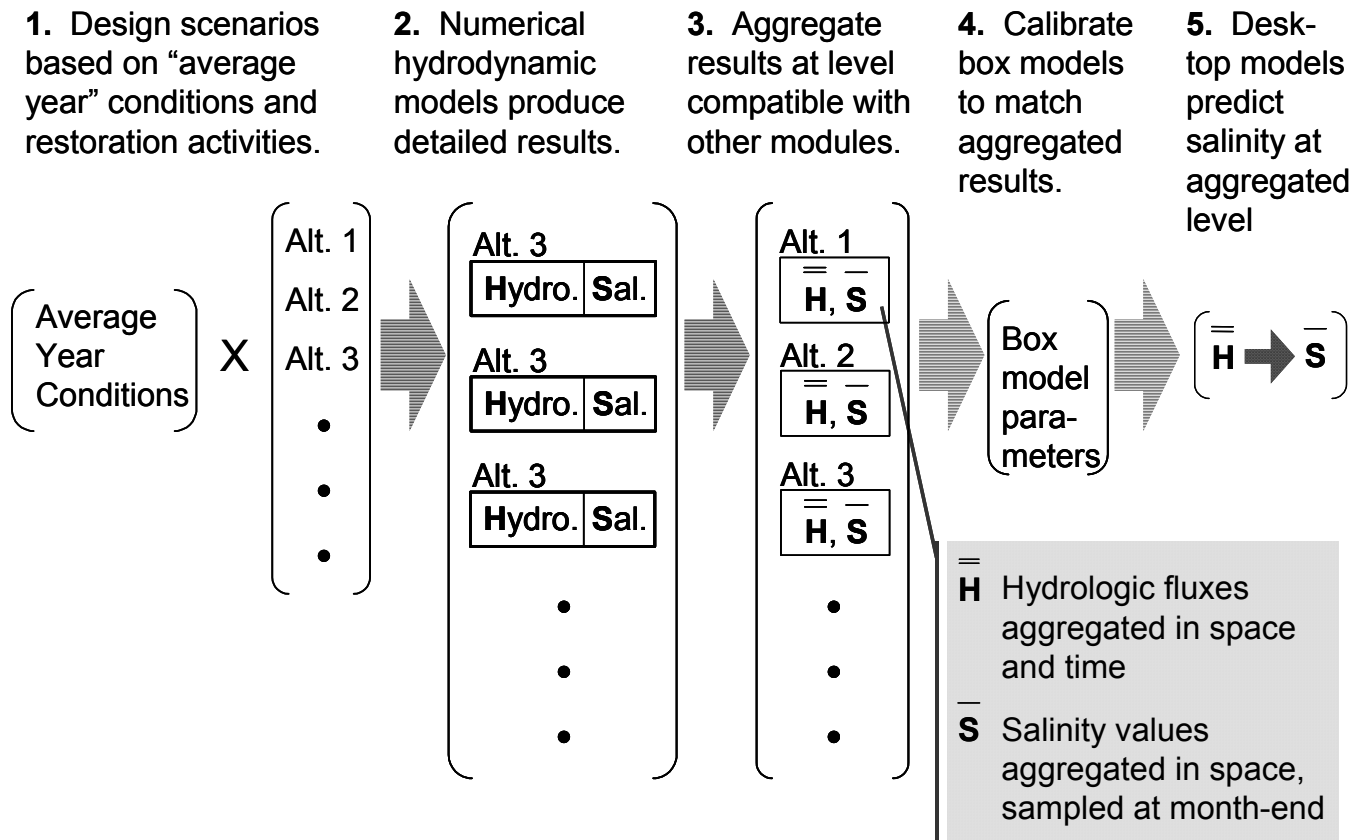$\overline{S}$ Salinity values aggregated in space, sampled at month-end

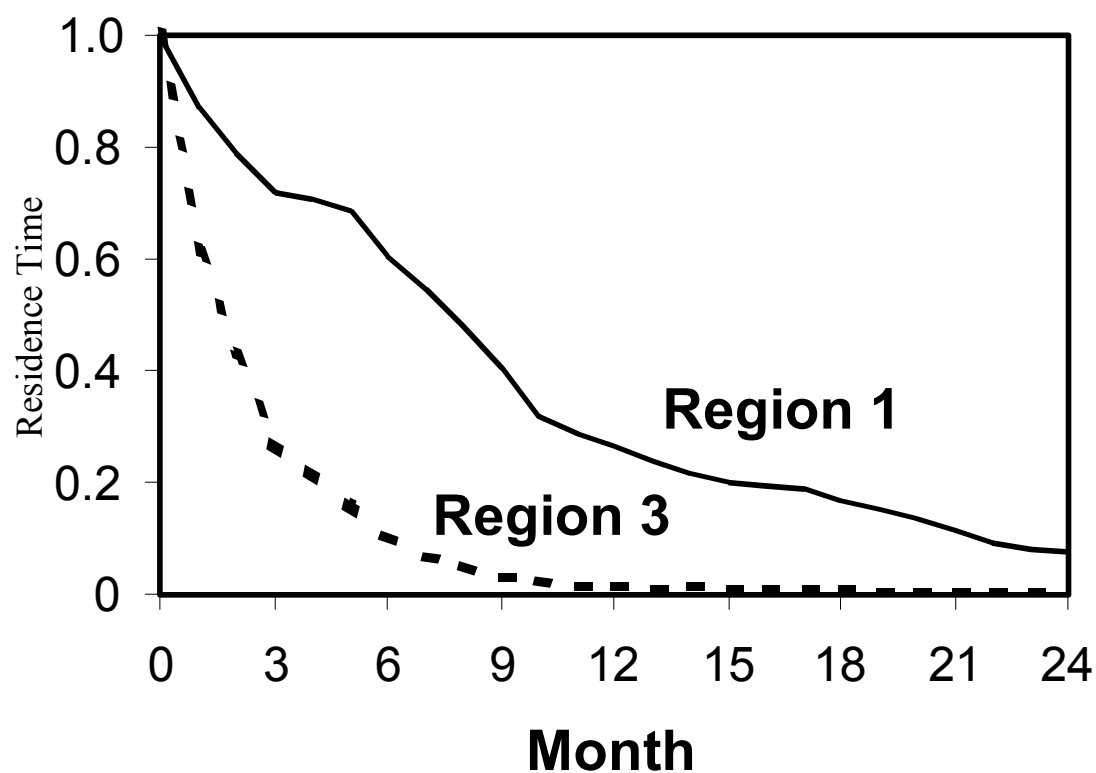**Figure C.7-2   Process of calibrating mass-balance models based on results of hydrodynamic models**

Figure C.7-.3 Residence time for mixing can be inferred from the decay in concentration of a conservative tracer in the model

(Example from Florida Bay: these results imply a residence time of about 9 months for Region 1 and 2.5 months for Region 3.)